Path Loss Propagation Model Prediction for GSM Mobile Networks in Nigeria

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Abstract
Propagation path loss has great impact on the quality of services delivered by mobile communication companies. Accurate determination of propagation path loss leads to the development of efficient design, operation of high quality and capacity network. There are a lot of path loss models developed by previous researchers; however such models cannot be generalized to all environments. This research is aimed at predicting propagation path loss model which can be helpful in planning the best Global System for Mobile Communication (GSM) networks in Dutse town, Jigawa state Nigeria. The methodology employed is measurement and instrumentation method. Digital wheel meter and handheld Spectrum analyzer (AAronia AG HF 2025E spectran) were used to measure signal path loss at Garu, Fagoji, and Takur and Gida dubu sites in Dutse town respectively. The outdoor fields' measurements were carried out at 900MHz frequency range. The average path losses measured and predicted are 75.70db, 70.20db, 78.30db, 76.10db and 80.10dB, 74.27dB, 80.89db, 82.30dB for Airtel, MTN, Glo and Etisalat respectively. The variance of these average values lies between 2 to 7dB which is within the acceptable range. This shows a significant correlation between the measured and predicted models. Therefore the empirical model developed from Log-Normal shadowing concept can work for GSM network service providers for planning and optimization their services in Dutse, Nigeria.

Index terms: *GSM Network Service Providers, Path loss Measurement, Propagation Model, Planning and Implementation.*

I. Introduction

Access to Global system for mobile Communication (GSM) has dramatically increased in Africa since late 2000s. In Nigeria it became most active industry in 2004 to the present day. The quality of service provided by the key players in the industry becomes so worrisome by the users. The numbers of network service providers continue to increase, but the quality of services offer is poor due to several factors. Therefore, there is urgent need by NCC to checkmate the activities of these network service providers, in addressing the factors that militating against provision of excellent service to their teaming customers [1]. The investigation and identification of the possible factors and proper solutions through scientific findings became necessary towards solving problems faced by the customers. A research survey conducted by D. A. Shalangwa in 2012, through interview with cross section of GSM subscribers within the investigation areas shows there were difficulties experienced by the subscribers of these network service providers. The difficulties experienced by subscribers are; network busy, frequent call drops, an echo, is not available, poor inter and intra connectivity, cross talk interference during conservation and signal fading among others. Factor that affect GSM signal strength within the study area may include snow, fog, rainfall, propagation mechanism such as reflection, refraction, diffraction, scattering, free space loss, foliage and geographical features [2][3]. Wireless radio channels are hard to predict, because mobile radio channels have a random behavior unlike stationary line of sight channels. When considering wireless radio channels there is need to consider all the factors into account that transmission path could be in line of sight or could be obstructed with objects like buildings, mountain etc. when considering the case of wave propagation in urban environment then, we have multiple reflection from high rise buildings and many such types of objects under these circumstances, electromagnetic waves travel through different paths having varying length, when these waves interact at a point, the received signal generates multipath fading, due to these factors, the received waves have varying strengths and also depends on the distance between transmitter and receiver [4]. Therefore, this research is aimed at predicting propagation path loss model for four GSM network service providers within Dutse- town in some selected areas.

II. Review on Propagation Path Loss Models

A number of propagation models, both theoretical and empirical, are available to predict path loss over different types of terrain. However, this study reviews only four models as follows.

1. Free-Space Propagation Model.

In free-space, the wave is not reflected or absorbed. Ideal propagation implies equal radiation in all directions from the radiating source and propagation to an infinite distance with no degradation [6]. Free-space attenuation increases as the frequency, f (in MHz) goes up for a given unit distance d in (Km). Equation (1) below present the formula to calculate free-space path loss (PL_{fs}).

$$Pl_{Fs(dB)}=32.5+20\log(d)+20\log(f) \quad (1)$$

2. Keenan-Motley Model

In contrasts to the losses that account between the medium of transmitter and the receiver there are other losses that play a vital role when focusing on indoor environment such as floor separation and penetration losses due to walls. This is shown in equation (2) below.

$$PL_{fs}\,(d)=free-space+wall\ loss \quad (2)$$

Therefore, Keenan-Motley Model is given as;

$$L_{(dB)}=32.5+20\log(f)+20\log(d)+p*w(k)+k*f(k) \quad (3)$$

But the simplified form of the model is known as IB model using walls only which is given by

900MHz; $L_{(dB)}=91.5+20\log(d)+p*W(k)$ ....(3)

1800MHz; $L_{(dB)}=97.6+20\log(d)+P*W(K)$ ....(3)

IB model has been designed for two different frequencies. IB is more convenient to use.

3. Path loss slope model

Another model used to calculate path loss in indoor environment is the path loss slope. Path loss slope are attenuation slopes that are obtained from different indoor environment by performing large amount of measurements [7][12]. Path loss slope models obey the distance power law model as described in log distance model below

$$PL_{(dB)}=PL_{(do)}+10n\log(d) \quad (4)$$

Where, PL (do) is the path loss that is measured at 1Km distance which is given by $32.5 + 20\log(f) + 20\log(d)$ and n is the path loss slope coefficient. .

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4. Log-Normal Shadowing Model

In terrestrial wireless communication, signal propagation may be characterized by such factors as path loss, shadowing and fading. Path loss has been defined as the attenuation effect on the signal as it propagates from the transmitter to receiver. When the received signal strength gradually varies around its mean value, this phenomenon is called shadowing. While fading describes the frequent fluctuation in the received signal strength due to the arrival of the signal at different time as a result of multipath.

A simple power law path loss model [8] was chosen for predicting the distance over which a reliable communication link can be established between two mobiles. A modified version of the power law path loss model is given as [9]

$$Pl_{(di)}= Pl_{(do)} + 10n log_{(\frac{di}{do})} + X\sigma \ldots\ldots (5)$$

$$n= \frac{Pl\,(di)-PL(do)}{10\log(\frac{di}{do})} \ldots\ldots (6)$$

Where, $X\sigma$ is a zero-mean Gaussian distributed random variable (in dB) with standard deviation σ (in dB), which attempts to compensate for random shadowing effect where linear regression analysis is been employed , the path loss exponent n, can be determine (in mean-square error sense) the difference between measured and predicted values of the [6] to yield

$$n=\sum_{i=1}^{N}[PLM(di) - PLP(di)/\sum_{i=1}^{N} 10\log\left(\frac{di}{do}\right) \ldots \ldots (7)$$

Where P_{LM} (di) represent measured path loss and P_{LP} (di) represent predicted path loss at any distance di, n is the number of the measured data or sample points. The standard deviation is equally minimized as

$$\sigma=\sqrt{1/N \sum[Plm\,(di) - Plp\,(di)]^2 \ldots \ldots (8)}$$

Also, received power P_r in (dBm) at any 'D' from the transmitter, with transmit power P_t in (dBm) is given P_r (dBm) = P_t (dBm)-P_L (dBm)……………………………….. (9)

However, for 100m $\leq$ di $\leq$ 1Km using equation.

Therefore, $Pl_{(di)}= 10log_{(}(P_t/P_r)$ dB…………………………………………………(10)

Recall, path loss exponent indicates the rate at which path loss increases with distance. Path loss can therefore be estimated by using data obtained from field measurements, which are substituted into equation (6). $Pl_{(di)=}Pl_{(do)}\ \ +10nlog_{(\frac{di}{do})dB}$………………(11)

Where PL (do) is the reference path loss measured at the reference distance do, n, is the path loss exponent (usually empirically determine by data obtained from field measurements. It is significant to select a free space reference distance that is appropriate for the propagation environment. In large coverage cellular systems 1km reference distance is commonly used whereas in microcellular systems much smaller distance such as 100m to 1Km are used [10]. The reference distance should always be in the Far field of the antenna so that near field effect do not alter the reference path loss [11]. In this research work we desire to choose do=100m as a reference. The path loss exponent n then can be derived statistically between measured and predicted path loss. Refer to equation (6), the expression P_{LM} (di) - P_{LP} (di) is an error term with respect to n, and the sum of the mean square error, e(n) is therefore express as

$$e(n)=\sum_{i=1}^{n}[Plm(di)-Plp(di)]^2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (12)$$

The value of n which minimize the mean square error (MSE), is obtained by equating the derivative of equation (12) above to zero and solve for n

$$\frac{\partial(n)}{\partial n}= 0\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (13)$$

III. Investigation area and Methodology

Dutse Town is the capital city of Jigawa State, North-Western Nigeria. It is an urban city characterized by sites located near moderate and tall mountains, residential and commercials buildings as well as small scale industries and offices. The town has communication towers and high density of both human and vehicle traffic. The GSM service providers in the town are Airtel, MTN, Globacom and Etisalat operating between 900MHz and 1800MHz, with average base station antenna of 30 to 35M height, transmitting power within the average of 40W. The methodology employed for this study is measurement and instrumentation method. A digital wheel meter and handheld Spectrum analyzer (AAronia AG HF 2015E spectran) were used to measure signal path loss at Garu, Fagoji, Takur and Gida dubu sites in Dutse town respectively. The instrument were interfaced with LC software and PC to measure the received signal strength (RSS in dBm) while digital wheel meter was used to measure the distance from reference point of BTSs.

IV. Data Collection and Analysis

To derived and optimize empirical model suitable to the area under investigation, field measurements data of RSS were conducted. Table1 below shows the average values of the measured RSS and the corresponding values of the measured and predicted path losses for specific distances.

Table 1: Measured and Predicted path losses for Airtel Service Provider

Distance in 'm'	**Average power (RSS) in (dBm)**	**Measured P_{LM} in(di)**	**P_{LP} (di) in (dBm)**	**P_{LM}(di)-P_{LP}(di) in (dBm)**	**[P_{LM} (di)-P_{LP} (di) in (dBm)**
100	-50	66	66	0	0
200	-51	67	66+3.01n	1-3.01n	$1-6.04n+9.1204n^2$
300	-54	70	66+4.77n	4-4.77n	$16-38.16n+22.7529n^2$
400	-57	73	66+6.02n	7-6.02n	$49-84.28n+36.2404n^2$
500	-58	74	66+6.99n	8-6.99n	$64-111.84n+48.8601n^2$
600	-59	75	66+7.78n	9-7.78n	$81-140.04n+60.5284n^2$
700	-62	78	66+8.45n	12-8.45n	$144-202.8n+71.4025n^2$
800	-65	81	66+9.03n	15-9.03n	$225-270.9n+81.5408n^2$
900	-69	85	66+9.54n	19-9.54n	$361-362.5n+91.0116n^2$
1000	-72	88	66+10.00n	22-10.00n	$484-440n+100.00n^2$

Table 1, P_{LM} (di) is computed from equation (10) and P_{LP} (di) was computed from equation (11) using Pt = antilog (RSS/10), while the mean square error were determine using equation (12)

$e(n)=\sum[PlM\,(di)-PlP(di)]^2= 524.3969n^2-1656.56n+1425=0$ applying equation (13)

$$\frac{\partial(n)}{\partial n}= 2(524.3969n)- 1656.56=0$$

$$N= \frac{1656.56}{1048.7938} =\mathbf{1.6}$$

The standard deviation σ (dB), about a mean value is also evaluated using equation (8)

$\sigma = \sqrt{1/N \sum [Plm\ (di) - Plp\ (di)]^2} =$

$\sigma = \sqrt{1/10 \sum [524.3969(1.6)2 - 1656.56(1.6) + 1425]^2}$ = **3.6dB**

Substituting for P_L (do), n and σ to compensate for the error into equation (5) will lead to development of a modified Log-Normal Shadowing Empirical model for Dutse Town and its environs given by

P_L (di) = 66+10(1.6) log (di/do) + 3.6 (dB)

Therefore the resultant path loss model for Dutse town environment is P_L(di) = 66 +16log (di/do)

PL (di) = 66 +16Log (D) dB…………………………………………………(14)

V. Result

The procedure for measurement and derivation carried out leading to the determination of P_L (do), n and σ which result to the development of empirical model of Airtel, were repeated for the remaining network service providers selected for his research. Table 2 below present the result obtained for MTN, Globacom, and Etisalat under the same operating conditions.

Table 2: Comparing path loss exponent, Standard deviation and reference path loss

Parameter	**Airtel**	**MTN**	**Globacom**	**Etisalat**
N	1.6	1.7	1.6	2.1
σ in (dB)	3.6	3.1	2.4	5.2
Path loss(do) in (dB)	66	60	68	63

The path loss values were substituted into equation (5), and the modified Log-Normal Shadowing model for the respective becomes:

P_L (Airtel) (di) = 66 + 10(1.6) Log (di/do) + 3.6 (dB)……………………………(15)

P_L (MTN) (di) = 60 + 10(1.7) Log (di/do) + 3.1 (dB) ……………………………(16)

P_L (Globacom) = 68 + 10(1.6) Log (di/do) + 2.4 (dB) ……………………………(17)

P_L (Etisalat) = 63 + 10(2.1) Log (di/do) + 5.2 (dB) ……………………………….(18

Hence, equations 16 - 18 above were used to generate the data in Table 3 below. The data presents the measured path losses at different distance for the GSM operators in the investigated areas. It also present the average path losses for each network and comparism were made.

Table 3: Measured path losses from the proposed modified model

Distance in (m)	**Path loss in (dB) Airtel Network**	**Path loss in(dB) MTN Network**	**Path loss in (dB) Globacom Network**	**Path loss in (dB) Etisalat Network**
100	69.60	63.10	70.40	68.20
200	74.42	68.22	75.22	74.52
300	77.23	71.21	78.03	78.22
400	79.23	73.34	80.03	80.84
500	80.78	74.98	81.58	82.88
600	82.05	76.33	82.85	84.54
700	83.12	77.67	83.92	85.95
800	84.05	78.45	84.85	87.16
900	84.87	79.32	85.67	88.24

1000	85.60	80.10	86.40	89.20
Average	**80.10**	**74.27**	**80.89**	**82.30**

Table 4: Measured and Predicted path losses

	Airtel	**MTN**	**Globacom**	**Etisalat**
Average measured path loss in (db)	75.70	70.20	78.30	76.10
Average predicted path loss in (db)	80.10	74.27	80.89	82.30

Figure 1 and 2 below shows the graphical representations of measured path loss against distance and average measure propagation path loss respectively.

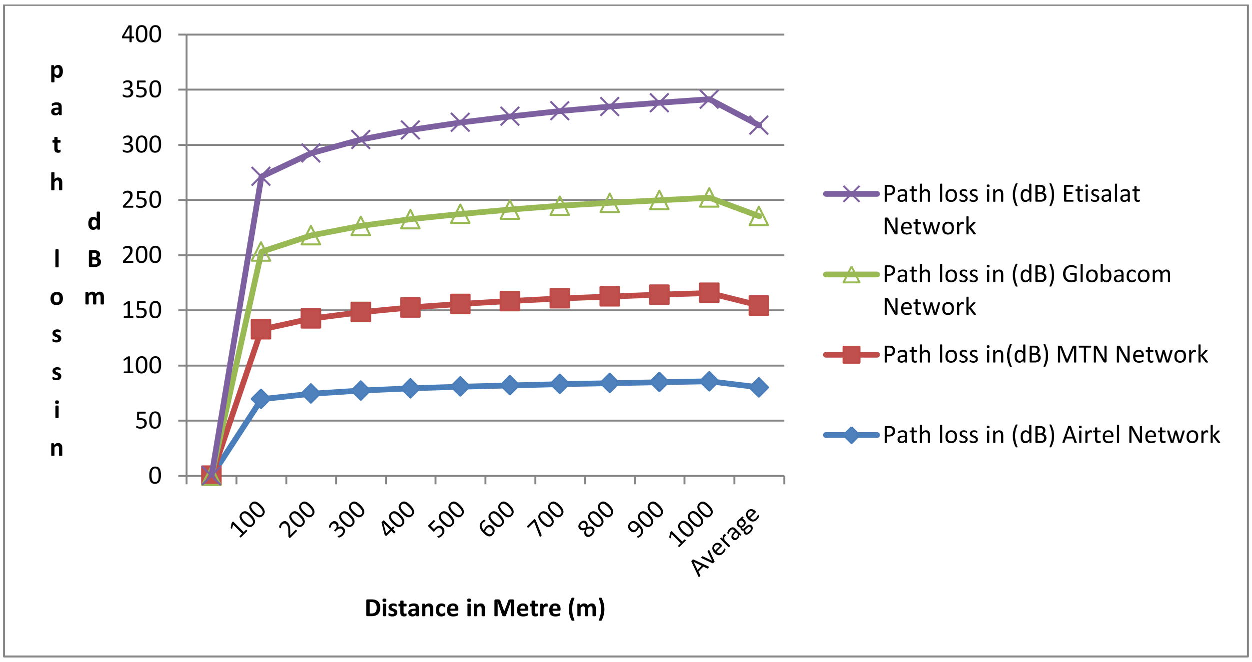

Figure 1: measured path loss against Distance

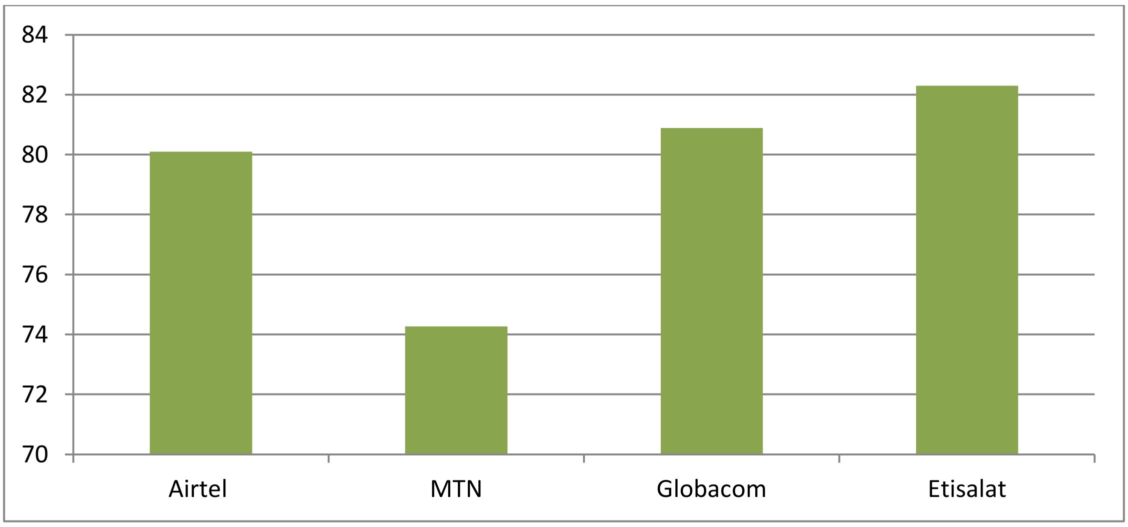

Figure 2: Average measure Propagation Path loss

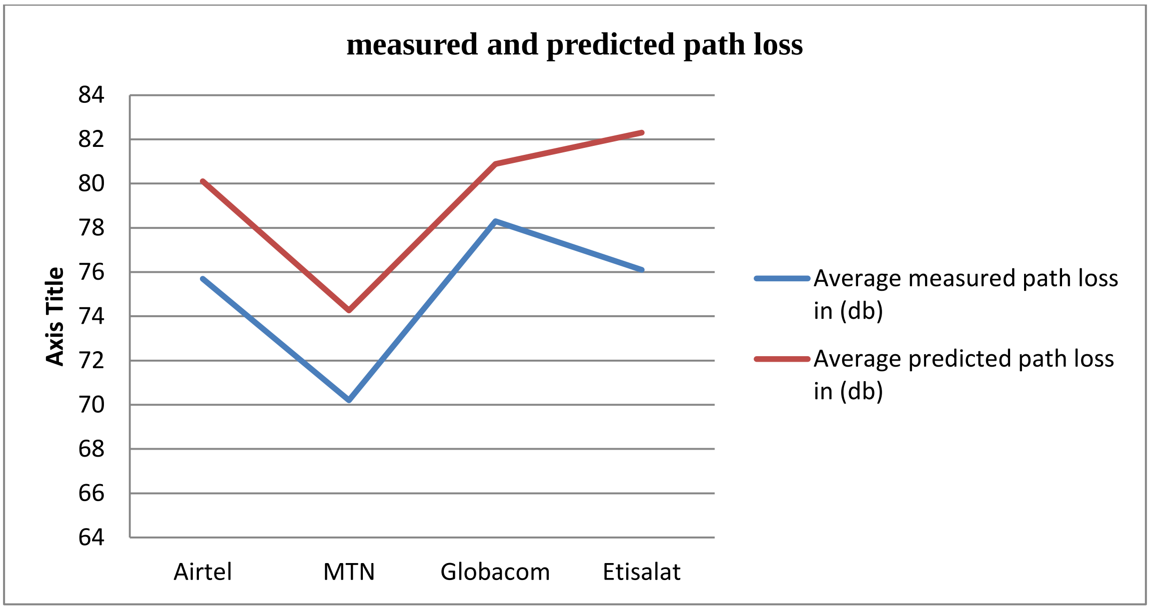

Figure 3: Average measured and predicted path loss

VI Discussion

Figure 1 presents path loss against distance for the GSM network service providers, considered in this research work. From the result graphically plotted, it shows clearly that path loss for the GSM operators increases at slightly different rates over the measured distance although its values vary from each operator. This is due to the location of the base station or height of the transmitting antenna and the compatibility of the environment, like trees, high rise up buildings and others factors in the area investigated. Figure 2 presents the overall average of propagation path loss measured for GSM operator; Etisalat network has the highest path loss great than that of Airtel, MTN, and Globacom with 8.03dB, 2.59dB and 2.20dB respectively.

VI. Conclusion and Recommendation

The empirical propagation model for planning and optimizing Global System for Mobile Communication (GSM) networks which addresses poor quality of services provided by GSM service providers in Dutse was developed. The average path losses predicted are 80.10dB, 74.27dB, 80.89 and 82.30dB, while the measured are 75.70, 70.20, 78.30 and 76.10 respectively. However, according to R. Rakesh 2012, the acceptable range between measure and predicted result lies between $1 \leq P_L \leq 20$dB. Therefore, the variations of the average values obtained lie between 2 to 7dB, which is within the acceptable range. Therefore, it can be concluded that the modified model developed from Log-Normal shadowing model can be useful to GSM network service providers for planning and optimization their services in Dutse, Nigeria.

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